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TOWARDS MINIATURE MICROBIAL FUEL CELLS FOR WATER QUALITY MONITORING

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***Abstract* – To ensure adequate sanitation of water supplies a rapid, cheap and simple method to test water systems is required. The microbial fuel cell (MFC) technology has potential for the effective testing of water sources in real time. A single chamber (68 µL) miniature MFC biosensor for detection of the biological oxygen demand (BOD) of water systems and to detect toxicants is presented. The device showed a response to a change in BOD within 19 minutes. The effect of operational conditions (pH, temperature, flow rate) on current generation was shown to have a maximum sensitivity of 0.944 µA cm^{-2} per unit change of the operational parameter. The power output of the device was enhanced by a factor of 28 by doubling the length of the anodic chamber and doping the cathode with a sustainable biochar based catalyst. The promise for detection of 'emerging' contaminants and toxicants in developing countries is discussed.**

***Index Terms* – Microbial Fuel Cell; microbial sensors; Toxicant; Water Quality**

I. INTRODUCTION

Thousands of different chemicals contaminate water systems. Their presence and biotoxicity must be quickly and efficiently assessed to contain the associated risks on the aquatic biota and human health.

Microbial fuel cells are devices that directly convert the chemical energy in organic matter into electricity via metabolic processes of microorganisms [1]. The current generated by an MFC directly relates to the metabolic activity of the electroactive biofilm at the anode surface [2]. Any disturbances of their metabolic pathways are translated into a change in the production of electricity.

If the MFC works at saturated fuel concentration and the operational conditions (pH, salinity, temperature and anode potential) are fixed, then variations in the current output can be associated with the presence of toxicants in the feeding stream. The MFC can therefore act as an indicator for biologically active compounds in water.

The main strength of the MFC technology relies on its simplicity. No external transducers are needed, as the presence of a pollutant in the feeding stream is immediately detected by a current change from the system. MFCs also lead to stable and cost-effective sensors that can operate infield, and continuously. Finally, the electricity generated by the MFC opens up the prospective for self-powering operations.

The work presented here looks at the use of miniature MFC-based sensors to assess the chemical and biological oxygen demand of water systems and to detect toxicants. The effect of a range of operational conditions on the MFC current (pH, temperature and flow rate), as well as methods of increasing energy generated in miniature devices by changing geometry and cathode catalyst is presented.

II. DEVICE

A miniature single MFC was constructed using a PDMS cast channel (4×4×4 mm^3 [L, W, H] anodic chamber, anode surface area 0.16 cm^2) sandwiched between two Perspex plates, Fig.1. Carbon cloth was used for the electrode materials. All tests were performed with three identical devices and the average response taken.

III. BOD SENSING

With acetate used as a fuel source for the MFC biosensor, the effect of altering acetate concentration between 10-600 mM was studied. The sensor was capable of monitoring changes in

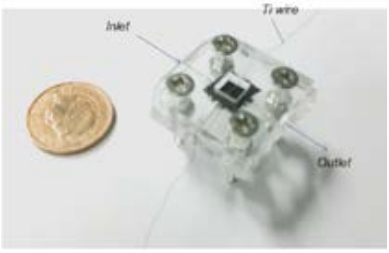

Fig. 1. Miniature single chamber MFC used in this work

the labile organic carbon content with response times on average of 19 minutes, with non-saturated conditions below 100 mM, Fig.2. For detecting toxicants in water sources the concentration of substrate must be maintained above this.

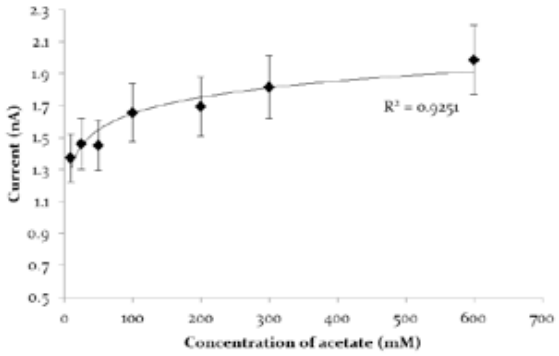

Fig. 2. Response of MFC unit to acetate concentration in feed stream, data is average of 3 MFCs with 12% error.

IV. Operational conditions

For sensing toxicants, operational conditions such as pH, temperature, and flow rate must be controlled. The effect of these parameters on the baseline current generation was studied.

The sensitivity of these parameters within a linear range can be determined by equation 1:

$$sensitivity = \frac{change\ in\ current\ (\mu A)}{unit\ change\ in\ parameter \times anode\ surface\ area\ (cm^2)} \quad (1)$$

The sensitivity of the MFC to temperature (15-35°C), pH (4.5-11) and flow rate (0.1-2.2 mL min^{-1}) was 0.020 µA $°C^{-1}$ cm^{-2}, 0.806 µA cm^{-2} and 0.944 µA mL^{-1} min cm^{-2} respectively. Death of the biofilm was observed at 50 °C and at flow rates exceeding 3.5 mL min^{-1}. Response times of the MFC sensor to operational condition changes were between 14-39 minutes.

V. Device geometry

To determine the effect of length on MFC performance, an additional MFC device was made with twice the length of the aforementioned device (8×4×4 mm [L, W, H], anode area 0.32 cm^2). Doubling the length of the anodic chamber enhanced the maximum power density of the device from 60 to 580 mW m^{-3}.

VI. Cathode catalyst

Usually Pt based catalysts are used at the cathode. The use of biomass based catalysts was studied for the purpose of sustainable enhanced power generation. Longer [L = 8 mm] MFC devices were prepared with 1.5 mg cm^{-2} of N/S/Fe-doped biochar doped onto the cathode, and their performance compared with MFCs without a cathode catalyst. The biochar improved the maximum power density of the device from 580 to 1680 mW m^{-3}.

VII. Prospective MFC Biosensing

The MFC biosensor presented in this work has proven to have suitable response times and good stability for use as a rapid, simple and cost-effective device to test water quality. Looking forward, the miniature MFC device will be used to detect toxicants relevant to developing countries (NO_3^-, heavy metals, etc.) and for 'emerging' toxicants (e.g. pharmaceuticals and their metabolites). Moreover field testing of real water systems will be pursued to ensure that the testing of multiple contaminants in water sources is feasible.

VIII. Conclusions

This work demonstrates the development of a miniature single chamber MFC biosensor for water quality monitoring. The sensitivity of the device to operational conditions such as temperature, pH and flow rate was no more than 0.944 µA cm^{-2} per unit change, and the device was responsive to changes in BOD within 19 minutes. The maximum power density of the MFC was increased by doubling the length of the anode chamber and by adding a biochar based catalyst to the cathode, with a combined improvement by a factor of 28.

The future research goals are to test this device against toxicants relevant to developing countries and against 'emerging' contaminants in water systems. Moreover, the challenges of contaminant mixtures will be addressed by field testing the device in real water systems.

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